EVALUATION OF DOUGLAS-FIR SEED MORTALITY ON THE CLEARWATER NATIONAL FOREST, IDAHO

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INTRODUCTION

Seed tree mortality is a persistent problem on U.S. Forest Service lands on the Powell Ranger District, Clearwater National Forest, Idaho, in spite of precautions taken in selecting trees and protecting trees while underburning. Post-fire examination on one particular site showed most trees to be infected with *Phaeolus schweinitzii* (Fr.) Pat. The disease had not been detected prior to marking the seed trees.

Tree stress and secondary insects have been linked to tree survival following fire damage (Ryan 1982a). Furniss (1965) found a strong association between fire damaged Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and Douglas-fir bark beetles (*Dendroctonus pseudotsugae* Hopkins). Vigorous trees (as measured by pressure bomb measurements of xylem pressure potential) are able to survive attack by "pitching out" the beetles making the attack unsuccessful (Ferrell 1978).

There is also a strong association reported between bark beetle attack and root disease infection. *Phaeolus schweinitzii* (Fr.) Pat. is a pathogen that primarily decays the heartwood of living trees seldom causing death unless associated with a bark beetle infestation or *Armillaria* root disease (Hagle 1981, Geizler *et al.* 1980). *Armillaria obscura* (Schaeff.:Secr), on the other hand, infects the sapwood and cambium and commonly predisposes trees to attack by bark beetles (Hadfield *et al.* 1986).

Root damage by fire has been associated with the physical effects of duff consumption on the site (Shearer 1975, 1976). Fine root biomass (roots less than 2 mm in diameter) is the component responsible for water absorbtion and uptake by the tree. The fine roots are concentrated in the top 15-20 cm organic layer of forest soil (McQueen 1973, Harvey *et al.* 1978). This vulnerable location exposes them to temperature changes from fire (Grier 1980, Vogt *et al.* 1980) and disruptions in the root production process.

Water stress as measured on a pressure bomb (negative bars of xylem pressure potential) (Ritchie and Hinckley 1975) has been studied to measure the impact of environmental effects or tree damage. Ferrell and Smith (1976, 1978) used xylem pressure potential to determine the indicators of (*Heterobasidion annosum* (Fr.) Brey.) root decay in white fir (*Abies concolor* (Gord. and Glend.) and the susceptibility to bark beetles. Waring and Cleary (1967) used xylem pressure potential to evaluate plant moisture stress during summer drought periods. Grissom (1985) found reduced water stress on trees with crown scorch and hypothesized that reduction of the transpiring surface in vigorous trees was responsible.

This study examined the possible causes contributing to the mortality of the Douglas-fir seed trees on a site on the Powell Ranger District, Clearwater National Forest, Idaho. The effects of fire, root disease and bark beetle infestation on water stress and fine root biomass were evaluated.

METHODS

Study Area

Three conifer stands one-half mile apart in the Lochsa drainage and similar in biological and physical type were selected for comparison on Powell Ranger District, Clearwater National Forest, Idaho. Aspects ranged from east to southeast, elevation 1340-1400 m (4400-4600 ft.) and slopes 50-60%. All sites had similar infection levels of *Phaeolus schweinitzii*. Habitat types are all in the *Abies grandis* (ABGR) series (Cooper *et al.* 1987) ranging from *Clintonia uniflora* to the *Asarum caudatum* habitat type.

Treatments

The stands each received a different treatment: (1) control (untreated) (2) seed tree cut and underburned, or (3) seed tree cut without underburning. The study trees were 200-250 year-old Douglas-fir on all three sites. Trees on the unburned stand were generally smaller in diameter, shorter, and averaged 50 years younger than those on the burned site. Trees on the burned site were selected from the survivors and were in various stages of decline.

Burned/Thinned Stand

The burned/thinned stand was harvested in 1982 with approximately 18 residual trees per acre of primarily Douglas-fir with some ponderosa pine (*Pinus ponderosa* Laws.) and western larch (*Larix occidentalis* Nutt.) over 42 cm (17 in.) d.b.h. (diameter at breast height or 1.4 m). This stand was underburned after harvest to reduce fuel loads and vegetative competition for natural regeneration.

Burning of the stand was accomplished two years before the initiation of this study. Slash was cleared in a 3.5 meter square area around the seed trees prior to burning. Pre-burn fuel loads were 21 tons per acre (6 tons/acre in the <1 inch size class) (Anderson 1982), fuel moistures were 8-17% for one hour fuels and the ignition pattern was a strip head fire. Burning occurred in 1983 with weather conditions within prescribed limits (22°C or 72°F and 42% no wind) to ensure minimum intensity and flame length (1.2 m or 4 ft.) for seed tree survival. The burn was observed to be light to moderate in intensity for a prescribed underburn. Observations showed maximum flame length of less than 2 meters (6 ft.) with an average of 0.9-1.2 m (3-4 ft.) and little smoldering combustion which is associated with high ground temperatures (Dave Thomas, formerly of Powell Ranger District, pers. comm.). Levels of damage to the residual trees were determined to be within acceptable limits based on post-burn analysis conducted in the same season. However,

heavy mortality occurred primarily in the Douglas-fir trees after the burn in 1984.

The predictions of tree mortality made with the tree mortality prediction model resulted in .1 probability of mortality given the average tree diameters of the underburned stand (Reinhardt and Ryan 1989). This is well below the resulting 40% mortality that occurred one year after the burn, indicating that this situation was not typical of most fire mortality cases.

Unburned/Thinned Stand

The unburned stand was harvested in 1981 with 12 trees per acre retained as a seed source.

Control Stand

This stand, adjacent to the burned stand on private land and similar in site characteristics, was used to sample for water stress only. No harvesting or burning occurred but infection by *P. schweintizii* was observed on the site.

Sample Selection

Fifteen trees were sampled in each stand representing the full range of crown symptoms including those trees without signs of disease infection. A dead tree was also included on both of the treatment sites.

Root Disease Infection

Extent of root disease infection was determined for a subsample of the root systems in the treated stands. Seven trees per stand were randomly selected, cut and the stumps were excavated using water gel explosives (Hagle 1981). Each root system was ocularly divided into cardinal (longitudinal) quadrants to detect root disease throughout the system. Within each quadrant, roots from three zones were subsampled at 1 meter from the root collar, one half meter from the root collar, and at the root collar; three diameter classes within each zone were sampled. Disease location was determined based on visual symptoms from cross-sections cut from each sample. Random samples of symptomatic roots were selected for fungus isolation to confirm pathogen identification.

Bark Beetle Impact

After trees were cut, bark samples measuring 20 cm X 20 cm were cut and removed from two sides (sun and shade) of the bole at three locations; 3 meters from the ground, 3 meters down from the 12 inch top diameter and half way between the first two locations. Square bark samples were cut and peeled off of the tree to examine for beetle galleries. Percent of sample that was occupied by larval galleries was recorded.

Direct Fire Impact

Direct fire damage was assessed on the burned site using methods described by Ryan (1982b) and Ryan and Noste (1983). These methods involved visual estimates of percent bole scorch, percent crown scorch, percent live cambium and ground char. Bole scorch was estimated on the circumference of the tree at d.b.h. (4.5 ft., 1.37 m). Percent of the original crown scorched by fire was visually estimated two years after the burn with the assistance of Kevin Ryan, U.S.F.S. Fire Research Lab, Missoula, Montana. Percent of the cambium at stump height that was alive was estimated with the use of a solution of orthotolidine (Ryan 1982b). Ground char was categorized from circular areas around the base of the tree to determine the amount of litter consumption and ground char that occurred (Ryan and Noste 1983).

Fine Root Biomass

Soil cores were taken to sample the fine root biomass. Samples were taken with a 10 cm X 30 cm tube driven flush into the ground. Two soil core samples were taken per tree 1 meter uphill and 1 meter downhill from the root collar. Fine Douglas-fir roots less than 1 mm diameter were separated, oven dried at 70°C for 48 hours and weighed.

Water Stress

Leaf xylem pressure potential was selected to test as a variable to represent the overall vigor of the tree. The leaf xylem pressure potential was measured at midday using pressure chamber methods of Ritchie and Hinckley (1975) on the burned, unburned and control stands. Branches with two years' growth from midcrown samples were used. Midday measurements were used in place of predawn measurements in an attempt to measure tree physiological water stress responses during periods of most active uptake and not soil water deficits.

Statistical Analysis

All samples were averaged and statistical tests were performed using SPSS-X and BMDP software. Analysis was done to evaluate the data for significance in variables between the treated sites to determine those that might be contributing to stress.

A test for homogeneity of variance was performed and results indicated analysis of variance (ANOVA) was not appropriate. Therefore, a Bonferroni's multiple comparison test was used to compare the xylem pressure potential between the three sites—burned, unburned and control. A student's T test was used to determine the significance of differences of all other variables between the burned and unburned site trees. Correlation coefficients were calculated for all variables on the burned site.

RESULTS

Root Disease Infection

The level of general root disease infection was similar on both sites based on the results of the statistical test (Table 1). There was clearly no significant difference between the average level of *P. schweinitzii* infection on the burned and unburned sites. On both sites many large roots were extensively infected by *P. schweinitzii.*

The extent of *A. obscura* infection was significantly higher at the root crown on the burned site. These data were supported by field observations. *Armillaria* incidence also appeared to be

greater on the burned site. Percent of trees on the burned site with *Armillaria* infection was 27% compared to 2% on the unburned site. The presence of *Armillaria obscura* in both stands seemed to be limited to dead or nearly dead trees.

Bark Beetle Impact

The average percent bark beetle girdling was higher but not significantly on the burned site (Table 1). Of the sampled trees infested, 55% of the infestations were found in the bottom portion of the bole compared with 35% in the middle portion of the bole. Many of the beetle galleries produced successful brood. Few galleries were observed to have resin that would indicate a wound response and resistance of a healthy tree to attack.

Direct Fire Impact

Duff consumption and ground char around five sample trees on the burned site was classified as moderate duff consumption with four classed as moderate or less ground char. For the observed flame length these classifications were determined to be insufficient to cause direct mortality (Ryan and Noste 1983). Root injury due to fire was sustained on only two main roots of one tree as observed in the root system excavation.

Fine Root Biomass

Fine root biomass averaged slightly less per tree core on the burned site than on the unburned site but was not significantly different (Table 1). These results are questionable due to the difficulty distinguishing Douglas-fir from the non-Douglas-fir roots.

Water Stress

The Bonferroni test for multiple comparisons indicated that the water stress (negative bars of xylem pressure potential) on the burned stand was significantly higher than the control stand at the 90% level of confidence (Table 1). The burned stand stress was not significantly higher than the unburned stand. However, environmental factors were not measured and the pressure readings were not adjusted to reflect the diurnal fluctuations inherent in the midday xylem pressure potential measurements.

Correlation Coefficients

Correlation coefficients in general were very low. No results were over $r=.77$. Some of the most highly correlated readings were between the degree of bark beetle or *A. obscura* infection and percent live cambium, percent bole scorch and percent crown scorch, in descending order (Table 2). Correlations within the fire damage variables alone were all very high—percent live cambium was highly negatively correlated with bole and crown scorch.

DISCUSSION

Root Disease Infection

Infection by *P. schweinitzii* alone seldom causes standing mortality except on rocky, dry sites in the northern Rocky Mountains. It predisposes host trees to infection by other pathogens such as *A. obscura* or to bark beetle attack (Hadfield *et al.* 1986, Hagle 1981). All of the trees sampled had high rates of infection by *P. schweinitzii*. The infection probably contributed to the visible decline and subsequent infection by *A. obscura* in conjunction with the effects of burning.

The significantly higher level of *A. obscura* ($P<.10$) on root crowns on the burned site follows patterns observed elsewhere. *Armillaria* has been observed to form localized, latent infections on Douglas-fir roots which become more active and extensive as the tree loses resistance (Wargo and Shaw 1985). Hagle (1981) found *Armillaria* invading and killing roots previously infected with *P. schweinitzii*. This would support the hypothesis that the combined effects of fire damage and *P. schweinitzii* infection would result in increased stress and infection by *Armillaria*. Once infected by *A. obscura*, the tree

Table 1.—Means and multiple comparison test using Bonferroni and Student's T test.

	BURNED SITE		UNBURNED SITE		CONTROL		P
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	
WATER Bars	15.6	(4.16)			12.9	(2.50)	0.08*
STRESS Bars	15.6	(4.16)	13.4	(1.98)			0.16
FINE ROOT (dry weight)	.47 gm	(.23)	.48 gm	(.26)			1.84
INFECTION All disease	77%	(.09)	79%	(.07)			.20
INFECTION *A. obscura*	27%	(.22)	2%	(.08)			0.10*
INFECTION *P. schweinitzii*	58%	(.27)	36%	(.42)			.34
10 YEAR GROWTH	14 mm (11/20")	(6.14)	18 mm (14/20")	(6.84)			0.56
BARK BEETLE	12%	(.20)	2%	(0.08)			.22

*Statistically significant at the 90% level of confidence

Table 2.—Correlation coefficients.

Variable		r	n	Sig
BARK BEETLE	w/ % live cambium	-.6992	15	.002
	w/ % crown scorch	+.4792	15	.035
	w/ % bole scorch	+.4450	15	.048
	w/ root biomass	-.2928	30	.058
	w/ A. obscura	+.2463	21	.141
	w/ P. schweinitzii	-.2042	21	.187
ROOT BIOMASS	w/ % root disease	-.5737	21	.003
	w/ % live cambium	+.3872	15	.077
	w/ % crown scorch	-.2493	15	.185
	w/ % bole scorch	-.0932	15	.370
	w/ water stress	-.2197	28	.131
% CROWN SCORCH	w/ % bole scorch	+.6624	15	.003
	w/ % live cambium	-.7712	15	.000
% BOLE	w/ % live cambium	-.6922	15	.002
	w/ water stress	+.6748	19	.001
A. obscura in Root Crown	w/ % live cambium	-.7376	10	.007
	w/ % bole scorch	+.4130	10	.117
	w/ % crown scorch	+.6481	10	.020

is further stressed by that infection. Root disease infection lowers the resistance of trees to secondary attack by bark beetles (Geizler *et al.* 1980, Hertert *et al.* 1975).

Bark Beetle Impact

The relationship between Douglas-fir beetle mortality and fire damage has been documented (Furniss 1965) as has the association between beetle mortality and disease infection (James and Goheen 1981, Hertert *et al.* 1975, Partridge and Miller 1972) and beetle mortality and water stress (Rudinsky 1966, Ferrell 1978). The slightly higher (although not statistically significant) level of cambium girdling by bark beetle ($P < .22$) on the burned site suggests the beetles played a similar role in this situation.

Douglas-fir beetle attacks in this study were most highly correlated with all forms of fire damage (Table 2). This follows similar patterns to those found by Furniss (1965). Location of attacks support this also because most attacks were observed in the lower portion of the bole where fire damage was concentrated on trees in the burned site.

Crown scorch, the second highest correlation with beetle damage, is the most common indicator of fire damage and is used to rate fire damaged trees for potential mortality (Ryan *et al.* 1988, Ryan and Reinhardt 1988, Reinhardt and Ryan 1989, Wyant *et al.* 1986, Peterson 1984, Bevins 1980, Furniss 1965). Peterson and Arbaugh (1986) found that crown scorch and insect damage were the best predictors for survival of Douglas-fir and concluded that crown scorch reduced the photosynthetic capacity of a tree lowering resistance to insect damage. The correlation between crown scorch and beetle girdling supports this pattern in spite of the lack of statistical correlation with moisture stress.

Direct Fire Impact

The contribution of fire to root system damage is a function of duff consumption and soil moisture reduction (Shearer 1975, 1976). The low levels of duff consumption and ground char in this study should have resulted in relatively light fire impact on the roots. In the large size class of roots (greater than 5 cm diameter) only two roots on one tree exhibited fire injury. Yet with a reduced root system due to root disease this damage may have been sufficient to affect the fine root production capacity. Ryan (1989) states that increased moisture stress, stomatal closure and reduced photosynthesis can result from a reduced root volume size.

In addition, the lethal rate of crown scorch is reported to be 60% for mature Douglas-fir (Norum 1977, Wyant *et al.* 1986). The average percent crown scorch measured in this study was 37%. This would also indicate that fire damage alone was not sufficient to cause high levels of mortality. Ryan (1989) and Chambers *et al.* (1986) state that vigor and crown ratio influence survival of mature trees with crown scorch.

Large trees are more resistant to fire due to bark thickness which reduces injury to the cambium (Ryan and Reinhardt 1988, Ryan *et al.* 1988, Peterson and Arbaugh 1986, Wyant *et al.* 1986) and higher crowns reducing crown scorch. The trees in this study would normally escape damage due to their large size class and the fact that the average percent live cambium was 79%. This is also confirmed by the results from using Reinhardt and Ryan's model (1989). Ryan *et al.* (1988) also found a high probability of mortality if greater than 25% of the cambium is dead at breast height. Ryan (1989) suggests that carbohydrate flow to roots may be disrupted with extensive cambial killing leading to moisture stress.

The relatively low percent of dead cambium directly from fire damage in this study suggests that cumulative effects must have played a part in the high rate of mortality. Several trees had greater than 25% dead cambium resulting from the combination of damages and have high probabilities of death. Increased conifer mortality when crown scorch was accompanied by root and bole damage was also observed by others (Peterson and Arbaugh 1986, Wagener 1961, McConkey and Gedney 1951). In this case, the damage was inflicted by pest interactions.

Fine Root Biomass

Damage to the root system by fire and disease infection would reduce the overall size of the system with consequences for water uptake. Due to the concentration in the top 15-20 cm of forest soil the roots are in a vulnerable location exposed to temperature changes from fire (Vogt *et al.* 1980). Harvey *et al.* (1978) also found the greatest number of ectomycorrhizal root tips in the organic soil fractions in Montana and suggested soil wood reduction would reduce mycorrhizae. These works imply that prescribed burning for site preparation would reduce the amount of fine root biomass produced.

Water Stress

The xylem pressure potential measurements documented here do not approach the extremes for water stress documented by other researchers. Base potential (predawn pressure potential) readings reported by Waring and Cleary (1967) for Douglas-fir at the peak of summer drought were -14 bars. Running (1976) reported diurnal xylem pressure potential thresholds of -20 bars in Douglas-fir in Oregon. As soil moisture appeared not limiting, it was hoped that midday water stress measurements would reflect the physiological stress imposed by fire, insect and root disease damage on water uptake and transport. The results were not conclusive as diurnal environmental changes were undoubtedly responsible for some of the differences in water stress readings.

The reduced root system size caused by root disease probably caused some reduced water uptake even though this was not reflected in the xylem pressure potential data. Teskey *et al.* (1985) found a decline in xylem pressure potential when half of the root system of *Abies amabilis* (Dougl.) Forbes was severed. Running (1980) found that water relations in lodgepole pine (*Pinus contorta* Dougl ex. Loud) were controlled primarily by root and soil resistance. Root systems reduced in overall size would be less likely to compensate for this resistance to produce a favorable flow of water.

CONCLUSIONS

The high frequency of mortality of unsampled trees in the burned stand reflects the combined impact of fire damage, bark beetle infestation and root disease infection. The level of fire damage on the burned site, as reflected by low crown scorch percents and relatively high percent live cambium, was judged not to be sufficient to cause death. Nevertheless, the combination of fire damage to some subsurface lateral roots, root system reduction by advanced *P. schweinitzii* and *A. obscura* infection and girdling of the phloem by beetle galleries resulted in stress of the residual trees based on crown condition (new branch growth, crown density) observations. Reduced water transport in the xylem due to infection and decay would also be a contributing factor.

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